

A New Role for the Lower Hybrid Drift Instability in Magnetic Reconnection

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One of the most challenging unsolved problems in the field of space and astrophysical plasmas is magnetic reconnection. In this fundamental process, field lines of opposite polarity are brought together and fused into a new magnetic configuration. The process of magnetic reconnection is observed in the Sun, in the Earth space environment, in astrophysics, and in nuclear fusion experiments. In our effort we address the mechanisms responsible for reconnection using simulation and theoretical tools developed at the Los Alamos National Laboratory (LANL) in the last few years and uniquely available to our research team.

Our work has led to a significant new discovery. A plasma microscopic instability, known as the lower-hybrid drift instability (LHDI) has been shown to have a new and unexpected role in the dynamics of plasmas. The new discovery comes from our combining innovative numerical methods with high-performance computing, based on state-of-the-art parallel implementations designed for the LANL Q machine. Thanks to our access to the world-class supercomputing facilities at LANL and to a new mathematical method developed at LANL (implicit Particle In Cell), we have been able to gain an understanding of the physical mechanisms behind the development of the LHDI and its effect on reconnection. We have demonstrated the mechanisms leading to the conversion of magnetic energy and the acceleration of particles in current carrying plasmas immersed in magnetic fields.

In a work recently published in *Physical Review Letters* [1], we simulated the lower-hybrid drift instability in an ion-scale current

sheet using a fully kinetic approach with values of the ion to electron mass ratio up to $m_i/m_e = 1836$. Such simulation is a first of a kind, as previous simulations were limited to unphysical mass ratios or insufficient system sizes. The simulation was made possible by our advanced computational methods and by a large-time allocation through the Institutional Computing Support on the Q machine.

As shown in Fig. 1, the LHDI is localized on the edge of the layer but its nonlinear development increases the electron flow velocity in the central region resulting in a strong intensification and bifurcation of the current density and significant anisotropic heating of the electrons. This dramatically enhances the collisionless tearing mode and leads to the rapid onset of magnetic reconnection for current sheets near the critical scale.

We have applied our new understanding to the study of magnetic reconnection in the near Earth space, comparing successfully our simulation results with the results of the latest space missions, such as CLUSTER.

Magnetic reconnection occurs in natural systems and in fusion devices, issues of primary interest to DOE basic science and fusion energy missions. Our simulation effort and our comparisons with satellite observations test the predictive capabilities of existing codes and helps the efforts to predict space weather, an important need for space operations and homeland defence.

- [1] W. Daughton, G. Lapenta, and P. Ricci, "Nonlinear Evolution of the Lower-hybrid Drift Instability in a Current Sheet," *Phys. Rev. Lett.* **93**, 105004 (2004).
- [2] G. Lapenta, "A New Paradigm for 3D Collisionless Magnetic Reconnection," *Space Sci. Rev.* **107**, 167 (2003).
- [3] G. Lapenta, J.U. Brackbill, and W.S. Daughton, "The Unexpected Role of the Lower Hybrid Drift Instability in Magnetic Reconnection in Three Dimensions," *Phys. of Plasmas* **10**, 1577 (2003).



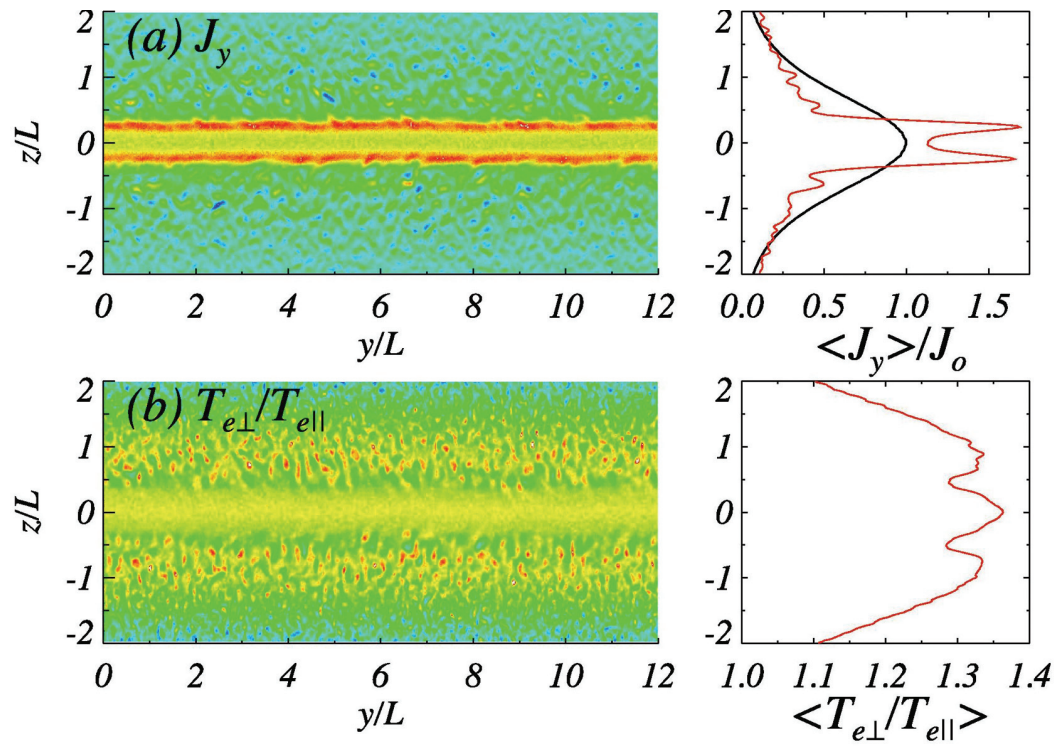


Figure 1—
Late-time evolution of the LHDI: (a) current density and (b) electron anisotropy. The averaged profiles (red) and initial current density (black) are shown on the right. The crucial point is that the nonlinear evolution of the LHDI gives rise to a peaking of the current density and anisotropic heating of the electrons in the central region of the current layer. Both of these can lead to rapid large-scale reconnection.